AD-A039 521 DEFENCE RESEARCH ESTABLISHMENT OTTAWA (ONTARIO) F/G 10/3
NICKEL/CADMIUM AIRCRAFT BATTERIES: BATTERY ALARM UNIT.(U)
APR 77 K FELDMAN, R M HAYASHI

UNCLASSIFIED DREO-TN-77-7 NL

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TABLISHMENT OTTAWA

DREO TECHNICAL NOTE NO. 77-7
DREO TN 77-7

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K. Feldman and B.M. Hayashi

CAUTION

RESEARCH AND DEVELOPMENT BRANCH

DEPARTMENT OF NATIONAL DEFENCE
CANADA

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

9 TECHNICAL NOTE NO. 77-7

14 DREO-TN-77-7

6

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Rechargeable Systems Section
Electrical Power Sources Division

11 Apr 77

12 18p.

PROJECT NO.
54-03-07

RECEIVED APRIL 1977
PUBLISHED APRIL 1977
OTTAWA

*On contract from Computing Devices Company

77-086

404 576

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ABSTRACT

Malfunctions in nickel/cadmium aircraft batteries which may lead to dangerous thermal problems are usually preceded by small atypical decreases in voltage of a single failing cell. Early detection of this decrease can provide time for suitable measures to be taken before other cells are damaged and catastrophic consequences occur. Also detection during battery shop operations can facilitate the screening out of defective cells.

The battery alarm unit described in this paper was developed at DREO and is a simple device which monitors the cell voltages by comparing the voltage in one half of the battery with that of the other half. Only three connections to the battery are required. Atypical voltage changes in a single cell, of the order of 50 mV may be detected. The precise sensitivity may be varied by varying resistor values in the input network.

The instrument has been found useful in the battery shop both for warning of failing cells in batteries being charged and for attracting attention to cells which show low capacity while being discharged. Presumably the instrument could be equally useful as an early warning device on aircraft. For such applications consideration must be given to questions of procedure, configuration and airworthy mechanical design. Also experience in the field is required on which to base decisions on the optimum sensitivity and whether aircraft and battery shop applications require the same sensitivities.

RESUME

Les défaillances des accumulateurs d'aéronefs au Nickel-Cadmium qui peuvent provoquer un emballement thermique dangereux sont habituellement précédées d'une faible baisse de tension aux bornes d'un seul accumulateur défectueux. Une détection rapide de cette baisse de tension permettrait éventuellement d'eviter que d'autres accumulateurs soient endommagés ce qui serait catastrophique. De plus, la même détection effectuée à l'atelier des batteries aiderait à rejeter les accumulateurs défecteux.

Le CRDO a mis au point un appareil, qui joue le rôle de systéme d'alarme et qui permet de détecter trés tôt les accumulateurs défectueux en comparant la tension de la premiére moitié des accumulateurs de le batterie avec celle de l'autre moitié. Cet appareil ne requiert que trois connexions à la batterie et permet de détecter une baisse de tension de l'ordre de 50 mV sur un accumulateur. La sensibilité peut être modifiée en variant les résistances du réseau d'entrée.

Dans les ateliers d'entretien, l'appareil a déjà démontré son utilité dans la détection des accumulateurs défectueux lors de la charge des batteries et des accumulateurs qui démontrent une faible capacité lors de leur décharge. Cet appareil pourrait aussi servir de systéme d'alarme à bord d'aéronefs. Il faudrait alors prendre en considération la configuration et l'encombrement de l'appareil et déterminer sa mode d'emploi. Il nous faut aussi plus d'expérience pratique pour établir la sensibilité optimale et pour décider si les appareils utilisés en atelier devraient avoir la même sensibilité que les appareils d'aéronefs.

INTRODUCTION

The "battery alarm unit"* described in this paper can be used in two different applications to improve the reliability and safety of nickel/cadmium aircraft battery operation. It can be used as an early warning device in an aircraft (or other user vehicle) where the instrument can indicate when a battery malfunction is developing. Secondly, in the battery shop it can be used during battery servicing procedures to attract attention to a cell which requires special investigation. Laboratory tests have established the basic principle for both applications and experience in two Canadian Forces battery shops has confirmed the utility of the instrument in the latter application (1). No attempt has so far been made to use the unit in an aircraft and no consideration has been given to details required for this application, such as airworthy construction, suitable configuration, procedures, etc.

This paper describes the battery alarm unit and its applications to nickel/cadmium batteries in the military sphere but, except for minor procedural details, it is equally useful in any other application of such batteries.

THE NEED FOR EARLY WARNING OF BATTERY FAILURE IN AIRCRAFT

The use of nickel/cadmium batteries in aircraft has been accompanied by the concern about what is frequently termed "thermal runaway" of those batteries. In actual fact, several different processes may lead to battery failures accompanied by excessive temperatures. However, it seems likely that there is a great preponderance of cases in which battery failures are initiated by failure mechanisms in a single cell. If this mechanism is allowed to continue, ensuing damage to other cells may compound the seriousness of this situation as well as cause unnecessary damage.

*DREO Invention No. 10-/74

It is important, therefore, to detect the onset of a single-cell failure at as early a stage as possible. This cannot be done by use of either a loadmeter or by temperature measurements at one or a few locations on the battery (2). In the case of the latter, a cell remote from a sensor may not only start to fail but may heat up to the point where the cell case is ruptured before the heat reaches the temperature sensor. Also the effect of an early stage of failure of a single cell is insufficient to influence the charge rate of the total battery sufficiently to be recognized on the loadmeter.

Thus there is a need to detect cell failures at an early enough stage to enable measures to be taken to minimize the danger to the aircraft as well as to minimize the damage to the battery but present facilities do not provide the means to satisfy this need.

CELL FAILURE DETAILS

The manner in which the battery alarm functions is predicated on the fact that most cell failures exhibit the characteristics described below.

(a) Badly deteriorated cellophane in the separator permits large quantities of oxygen to reach the cadmium plate during overcharge. The resulting reaction (3,4) generates large quantities of heat and causes discharge of the cadmium electrode. These cause the cell voltage to drop progressively as the process continues.

(b) Breaks or holes etc. in the cellophane (or substitute material) permit metal particles from the plates to be deposited in the mesh of the woven layers of the separator material. The accumulation eventually forms conductive bridges between adjacent plates through the holes in the cellophane. The resistance of these bridges is very high at the outset but falls as more and more metal is deposited in the bridge. At some point in time the conduction of the bridge becomes sufficient to start dropping the cell voltage slightly. As the accumulation continues still further the conductivity increases at ever accelerating rates until a massive short circuit results.

(c) A rough edge on a plate or at a plate connection wears a hole through the separator material to create a short circuit. Depending on the location and nature of the projection, etc. the rate of short circuit development may vary, but frequently the initial manifestation is a slow decrease of cell voltage.

It may be noted that all three of the above failure modes, which probably cause the majority of on-board catastrophic battery failures, start with a small decrease in cell voltage.

The problem, then, is to detect this small voltage decrease which may occur in any one cell of a 19 or 20 cell battery, and to differentiate between it and the normal variations between discharge and charge voltages which may be ten times as great. If this can be done a warning may be provided that a cell failure leading to thermal problems in the battery is imminent.

DETECTION OF CELL VOLTAGE VARIATIONS

One approach in attempting to detect anomalous decreases in cell voltages is to scan repeatedly the voltage of each cell in the battery, store the data obtained, compare successive values for each cell and interpret the results. The interpretation requires consideration of simultaneous factors such as whether the battery was undergoing high-rate discharge, going into overcharge, etc. The above method implies electrical connections to each of the 19 cells, suitable instrumentation and an on-board computer or its equivalent to perform the computations and logical decisions.

The battery alarm unit described here was designed in an attempt to enable the above tasks to be carried out without the expense and complexity of the multiple connections and computer. The unit is a comparatively simple device and accomplishes the task in an extremely simple manner while introducing only relatively minor procedural complications during certain pre-identified brief periods of battery usage. Also the need for connections to each cell is avoided. Only three connections to the battery are necessary. Procedural techniques to deal with the special periods referred to above are discussed in a subsequent section.

Normally a battery in an aircraft may be partially discharged during preflight operations and by in-board engine starts. Subsequently the generators supply electric power for use in the aircraft and for recharging the battery. The latter may occur in a relatively short time. During the remainder of the operational period, a trickle charge flows through the battery. It is during this period that most "thermal" battery failures occur and during which the need to monitor the battery behaviour is most critical.

It has been observed in the laboratory that the individual cell voltages may differ slightly from each other. However, the variations in these voltages during trickle charging tend to be the same for all cells in a battery. (This is also the case at other times except during high rate charges and discharges, and during entry into overcharge). Self discharge in a cell lowers the voltage of that cell in an atypical fashion. Since this is so, the total voltage of one half of the cells in the battery may be compared with the total voltage of the other half of the battery, and an atypical change in the total for either half can be detected.

The battery alarm is connected between the two terminals of the battery with a third connection to a point electrically between cells 9 and 10, i.e. electrically approximately half way between the terminals. A control is set to compensate for the fact that there are nine cells on one side and ten on the other, and for any minor differences which may exist between the two groups of cells. The instrument now "monitors" the "voltage balance" between the two sections of battery. An atypical change in voltage in any cell destroys the balance and a warning is produced.

More detailed descriptions are given in subsequent sections of this paper.

BATTERY SHOP APPLICATIONS

The battery shop may, of course, use the battery alarm in the same way as that described for aircraft, i.e. during the time the battery is being charged. However, an additional application appears to be very useful since it attracts attention to defective cells which may otherwise go undetected.

When a battery is removed from an aircraft for processing through the battery shop, it may be in a charged condition. It is connected to an automatic charger-analyzer unit (such as PCA 130 or PCA 131) which discharges it in a predetermined manner and for a set period of time. If the battery voltage does not fall below 19 volts during this time, the process of charging is carried out automatically. Otherwise the attention of the operator is attracted. Should a cell contain a developing short circuit path which has previously only partially discharged the cell, it is possible that this cell will be completely discharged and reversed during the above discharge period. However, if the remaining cells have somewhat greater capacity than the nominal value (and most do), the total voltage of the battery may remain above 19 volts in spite of the reversed cell. In that case the operator is not alerted to the presence of the defective cell and it may be recharged with the others to be unwittingly put back into service. The battery alarm unit, however, may be used during discharge in exactly the same manner as during charge. When the defective cell nears its discharged state before the other cells, its voltage drops faster and the battery alarm immediately attracts the operator's attention. He can then investigate and take any necessary action. Such cases have been experienced in the preliminary application in the battery shop of the battery alarm unit.

It seems probable that a somewhat similar use could be made of the battery alarm to detect cells that partly self discharge overnight on board the aircraft. This checkout could be done during inspections on aircraft fitted with alarm units, by recording battery alarm balance settings. Such a possibility has not been investigated.

BATTERY ALARM UNIT

The following sections describe the appearance and operation of the unit and give a brief description of the circuit. It should be noted that the configuration described is that of the experimental units. The instrument is a standard off-the-shelf box, and the circuit is mounted on a generalized printed circuit board intended for experimental work. Thus the size of the unit is larger than that which could be achieved with a specifically designed configuration. Also details pertaining to switching and indicators need not remain as they are presently arranged in the experimental design. Remote location of various components of the unit should also be possible.

DESCRIPTION AND OPERATION

A photograph of the experimental unit is shown in Figure 1.

The three battery connections are made to the terminals shown on the left front, and right sides of the box respectively (right hand terminal to the positive terminal on the battery, left hand terminal to the negative battery terminal and the centre terminal to a point on the battery electrically between cells 9 and 10). These connections provide both the power to operate the unit and the signals required to monitor the battery behaviour. The power required to operate the unit is negligible, being less than 0.1A normally and less than 0.2A when producing both audio and a visual alarm.

When the battery leads are connected and the power ON/OFF switch is "on", the BALANCE control may be adjusted. The unit indicates an alarm (by illuminating the alarm light and, if the SOUND SWITCH is "on", by generating an audio signal) for all settings of the balance control except for a limited range in the "balance" area. The procedure, then, is to find this area by rotating the control back and forth until the alarm ceases. The limits of the area are found by more slowly rotating the control in each direction to find the two points where the alarm starts. The control is then set midway between these points. A subsequent anomalous change in the voltage of any cell which exceeds the threshold sensitivity of the instrument will cause an alarm.

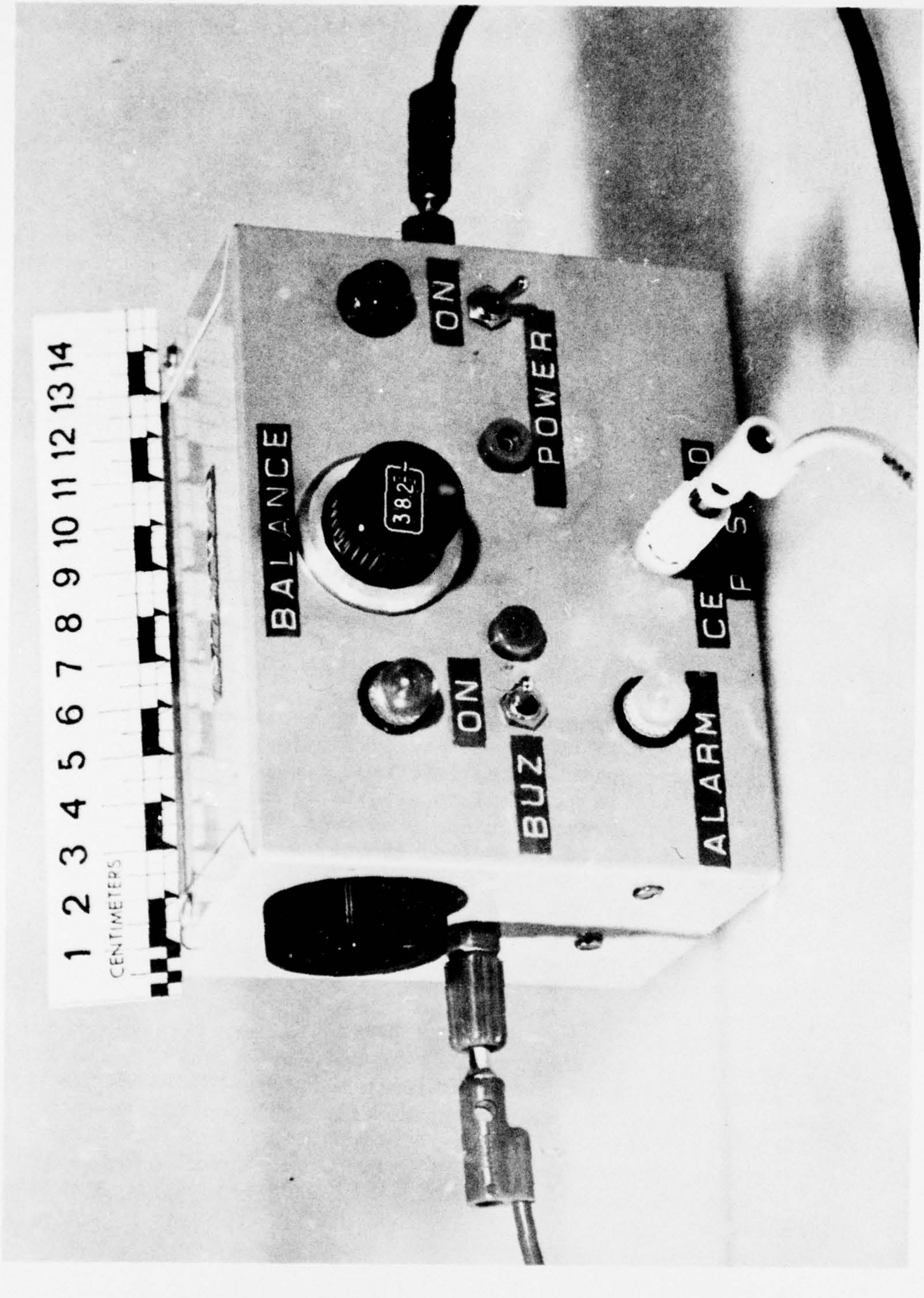

Fig. 1: Battery Alarm Unit - Experimental Model

CIRCUIT DESCRIPTION

Figure 2 shows a block diagram of the battery alarm circuit. The "input network" receives the input signals from the positive and negative battery terminals and from the connection between cells 9 and 10. The latter input is regarded as the "zero" level for the system and is also connected to the mid point in the "off balance detector" block. When the "balance" in the input network is properly adjusted, the inputs to the "off balance detector" are of equal magnitude and opposite polarity. In this condition the detector output is negative and the "amplifier" in the next block is cut off. This leaves the "alarm indicators" inactive.

Any change in the voltage of a cell which exceeds the threshold value and is unmatched in the other half of the battery, causes the off-balance detector to give a positive output. The amplifier consequently activates the alarm indicators.

The above mentioned threshold is chosen to give as early a warning of a malfunctioning cell as possible without excess sensitivity to minor insignificant fluctuations such as those due to differential temperature changes. Under laboratory conditions the threshold was set at 40 or 50 mW. Should field conditions indicate a need for altering the sensitivity, this may be done by altering values of resistors in the input network circuit.

A schematic circuit diagram of the battery alarm unit is given in Figure 3.

PROBLEM AREAS

As mentioned in an earlier section, the battery alarm unit accomplishes a complex task in a simple manner but introduces certain complications during certain brief periods of battery usage. These periods in themselves are not very significant in that there is no urgent need to detect the development of the pertinent malfunctions during those brief periods. The basic assumption that all of the normal cell voltages in a battery vary in a like manner does not necessarily hold true during high rate discharges nor during the period when the individual cells are beginning to go into overcharge. Also it is possible that the balance point for the alarm unit may be slightly different when the battery is in overcharge than when it is not. These problems are discussed in the following paragraphs.

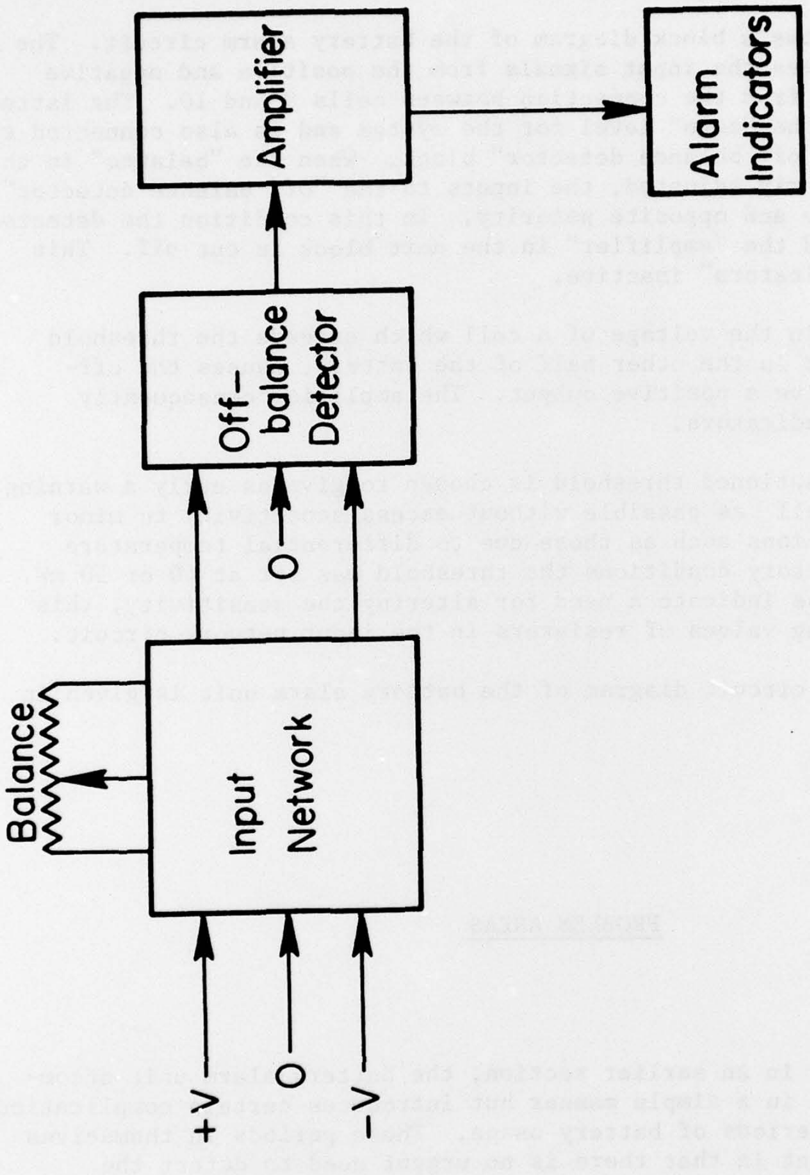

Fig. 2: Battery Alarm Unit - Block Diagram

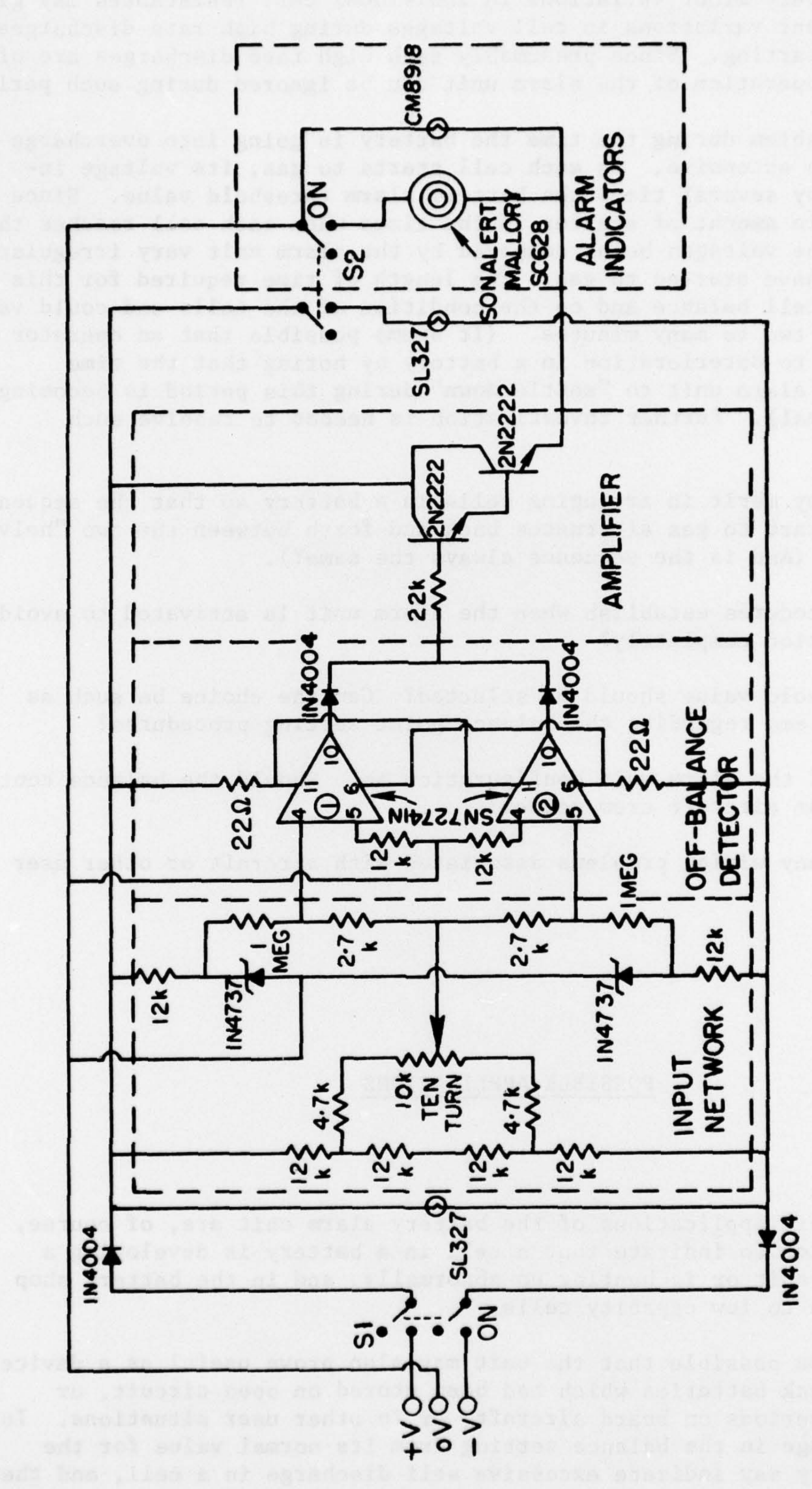

Fig. 3: Battery Alarm Unit Schematic Circuit Diagram

Relatively minor variations in individual cell resistances may give rise to significant variations in cell voltages during high rate discharges such as engine starting. Since presumably such high rate discharges are of short duration, operation of the alarm unit can be ignored during such periods.

The problem during the time the battery is going into overcharge is considerably more extensive. As each cell starts to gas, its voltage increases rapidly by several times the battery alarm threshold value. Since there is a certain amount of scatter in the times when each cell reaches the gassing state, the voltages being compared by the alarm unit vary irregularly until all cells have started to gas. The length of time required for this depends both on cell balance and on the condition of the cells and could vary from a minute or two to many minutes. (It seems possible that an operator could be alerted to deterioration in a battery by noting that the time required for the alarm unit to "settle down" during this period is becoming greater than normal). Further investigation is needed to resolve such questions as:

(a) Is there any merit in arranging cells in a battery so that the sequence of cells which start to gas alternates back and forth between the two "halves" of the battery? (And is the sequence always the same?).

(b) Should procedures establish when the alarm unit is activated to avoid the transient period completely?

(c) What threshold value should be selected? Can the choice be such as to minimize problems regarding the balance point setting procedures?

(d) What should the alarm unit configuration be? Should the balance control be available to an aircraft crew member?

(e) Are there any wiring problems associated with aircraft or other user situations?

POSSIBLE APPLICATIONS

The basic applications of the battery alarm unit are, of course, as a warning device to indicate that a cell in a battery is developing a serious short circuit or is heating up abnormally, and in the battery shop to draw attention to low capacity cells.

It seems possible that the unit may also prove useful as a device with which to check batteries which had been stored on open circuit, or after quiescent periods on board aircraft, or in other user situations. In such cases a change in the balance setting from its normal value for the particular battery may indicate excessive self discharge in a cell, and the

need for more extensive investigation. No attempt has so far been made to evaluate such uses of the battery alarm unit.

CONCLUDING REMARKS

The battery alarm unit is a relatively low cost, simple device which is simple to use. Its usefulness in the battery shop has already been demonstrated. It seems likely that reasonably simple procedures to avoid the complications occurring during the initiation of overcharge and during heavy discharge in aircraft could make it useful on board aircraft. In this application it seems likely that it would attract attention to the need for battery shop inspection of the battery as well as perform its main function: to warn of danger developing rapidly in the battery.

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA – R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATING ACTIVITY Defence Research Establishment Ottawa National Defence Headquarters Ottawa K1A 0Z4	2a. DOCUMENT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A
3. DOCUMENT TITLE NICKEL/CADMIUM AIRCRAFT BATTERIES: BATTERY ALARM UNIT (U)	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) TECHNICAL NOTE	
5. AUTHOR(S) (Last name, first name, middle initial) Feldman, K. Hayashi, R.	
6. DOCUMENT DATE MARCH 1977	7a. TOTAL NO. OF PAGES 11 7b. NO. OF REFS 4
8a. PROJECT OR GRANT NO. 54-03-07	9a. ORIGINATOR'S DOCUMENT NUMBER(S) DREO TECHNICAL NOTE NO. 77-7
8b. CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)
10. DISTRIBUTION STATEMENT UNLIMITED DISTRIBUTION	
11. SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY DAASE

13. ABSTRACT

Malfunctions in nickel/cadmium aircraft batteries which may lead to dangerous thermal problems are usually preceded by small atypical decreases in voltage of a single failing cell. Early detection of this decrease can provide time for suitable measures to be taken before other cells are damaged and catastrophic consequences occur. Also detection during battery shop operations can facilitate the screening out of defective cells.

The battery alarm unit described in this paper was developed at DREO and is a simple device which monitors the cell voltages by comparing the voltage in one half of the battery with that of the other half. Only three connections to the battery are required. Atypical voltage changes in a single cell, of the order of 50 mV may be detected. The precise sensitivity may be varied by varying resistor values in the input network.

The instrument has been found useful in the battery shop both for warning of failing cells in batteries being charged and for attracting attention to cells which show low capacity while being discharged. Presumably the instrument could be equally useful as an early warning device on aircraft. For such applications consideration must be given to questions of procedure, configuration and airworthy mechanical design. Also experience in the field is required on which to base decisions on the optimum sensitivity and whether aircraft and battery shop applications require the same sensitivities.

DSIS
72-508

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Security Classification

KEY WORDS

NICKEL/CADMIUM BATTERIES

WARNING OF THERMAL RUNAWAY

WARNING OF SHORTED CELL

EARLY WARNING

BATTERY FAILURE WARNING

BATTERY SHOP AID

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